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State of California
Highway Transportation Agency
Department of Public Works
Division of Highways

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S/A 13254 with
Supplements

Mr. J. A. Legarra
State Highway Engineer
Division of Highways
Sacramento, California

Dear Mr. Legarra:

Submitted for your consideration is a final report on:

"RECORDATION OF QUANTITIES OF MATERIALS

INCORPORATED IN

BASE AND PAVEMENT PLANT MIXTURES"

Research Study Conducted by..........Norman Pitt, Incorporated

Principal Investigator.....Norman Pitt, Norman Pitt, Inc.

Assistant Investigator.....Ugo Racheli, Norman Pitt, Inc.

Research Project Coordinators & Coinvestigators
(for California Division of Highways).......J. C. Obermuller &
Leigh S. Spickelmire

Final Report Prepared by....................J. C. Obermuller &
Leigh S. Spickelmire

Very truly yours,

J. F. Jorgensen

J. F. JORGENSEN
Construction Engineer

REFERENCE: Pitt, Norman; Racheli, Ugo; Obermuller, J. C.; Spickelmire, Leigh S.; "Recordation of Quantities of Materials Incorporated in Base and Pavement Plant Mixtures"; State of California; Department of Public Works; Division of Highways; Construction Department; Research Report F-0412; November 1968.

ABSTRACT: A determination is made that it is feasible to install an independent monitoring and recording system without reference to existing lever systems on weigh batching plants without thereby necessitating major modification of the primary weighing and control equipment. A load cell weighing system is shown to be the best means of performing the independent monitoring. More research under operating conditions is planned.

KEY WORDS: Bituminous mixing plants, concrete plants, construction materials, instrumentation, monitoring, quantity, recording systems, weight measurements.

ACKNOWLEDGMENT

This report is based on data collected during a research project financed by the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. The opinions, findings and conclusions expressed are those of the authors and not necessarily those of the Bureau of Public Roads.

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A. Synopsis

At present there is often inadequate assurance that materials metered or weighed in proportioning plants during construction of highway pavements, treated bases and structures are accurately measured in accordance with contract specifications. Such assurance is necessary for contract specification administration, quality of product and determination of payment.

The basis objective of this research project is to determine whether it is feasible to automatically record the data necessary to document proportioning operations in plants used for highway construction without also involving major modification of the primary plant proportioning equipment.

Briefly, the procedure followed was to contract with Norman Pitt, Incorporated, a qualified consultant in the plant manufacturing and instrument application field, to conduct a feasibility study of the concept and to prepare a report.

That report is included and made Part One of this document.

Mr. Pitt concludes that because volumetric proportioning is not common, the study should be limited to gravimetric batching plants and that it is both feasible and within the present "state-of-the-art" to apply a load cell system to the latter in a manner that will not interfere with existing manual or automatic operation but which will make it possible to weigh and record independently of errors in primary batching equipment.

An output of Mr. Pitt's study was the test data produced during one day of routine asphalt concrete weigh batching plant operation modified only by the addition of a trial load cell monitoring and recording system to the aggregate proportioning. Printed cards were obtained from the load cell system while the main plant aggregate scale indicator was photographically recorded. Batching operations were performed manually.

Mr. Pitt's report makes a limited analysis of this test data. Owing to its interesting nature, a more extensive analysis was subsequently undertaken and is described in Part Two of this document.

That analysis indicates a standard deviation of ± 0.2 percent is reasonable to assign to the load cell weighing system used in the Norman Pitt study and that a standard deviation of

± 18 pounds is a reasonable measure of accidental variation of manual manipulation for the particular plant utilized and for the specific test conditions.

Mr. Pitt's recommendations, that further research is indicated, and that a carefully engineered load cell monitoring and recording system should be installed in a modern, fully automated asphalt concrete weigh batching plant and thoroughly tested over a significant period, are sound and should be implemented.

A proved independent monitoring and recording system would enable a promising fresh approach to writing specifications for plant produced highway construction materials, would permit plant owners more flexibility in the selection of plant equipment, would encourage development of new and improved weighing and control mechanisms, and would make possible several important secondary benefits with respect to calibration of plant weighing systems and production of more economical pay records.

B. Background Information

In years past, proportioning plants were largely operated by manual methods and assurance that the materials were measured in accordance with contract specifications was provided through on-the-spot observation by engineering inspectors, a knowledge of the amounts of raw material delivered to the plant, and truck weights or other measure of the combined material produced.

Evolution has developed tremendously increased rates of production, enclosed plants, automatic operation, etc., so that on many modern plants the inspector virtually must rely solely on the mechanism itself. This is not infallible and is also subject to being overridden by the operator. Increasing emphasis on documentation of specification compliance poses a problem with atuomatic plants as well as the manually operated plants. Additionally, the need for economical use of engineering inspection manpower argues strongly against the "constant observation" method of control.

The most urgent reason to improve control assurance involves quality of the product itself. If a plant malfunctions, either through mechanical or human error, long stretches of pavement or whole structures can be produced and even put into use before deficiencies are noted.

Following are descriptions of some of the typical plant processes referred to above:

Plant-mixed Cement Treated Base

When produced by weight proportioning, two or more sizes of aggregate, stored separately, water and portland cement are batched into a mixer. The pay quantity for aggregate is determined by weighing the completed mixture (in the delivery vehicle on a platform scale) and deducting the amount of cement. Cement quantity is determined by scale weights as it is added to the mixture.

Operating tolerance for proportioning aggregate is required to be within 5 percent of the amount designated. A tolerance in weighing cement is not specified.

Asphalt Concrete

This operation is basically the same as that for Cement Treated Base, except that, of course, there is no portland cement and no water--usually only aggregate and hot liquid asphalt.

Pay quantity is determined by weighing the completed mixture and deducting the amount of asphalt (if paid as separate items). The pay quantity of asphalt is normally determined from the asphalt batch scale setting and number of batches. However, in some instances theorectical asphalt percentages must be used in calculating pay quantities.

The operational tolerance for aggregate and asphalt scales is 3 percent for any setting and 2 percent for any batch.

Portland Cement Concrete

The basic operation is also the same, except that payment is not based on the weights of the ingredients or of the freshly mixed concrete.

Batching tolerances for the weights of the ingredients are 1 percent for cement, 1-1/2 percent for any aggregate size and 1 percent for the total aggregate in any batch.

Additionally for pavement, automatic plant operation is required. The discharge mechanism of the cement weigh hopper must be interlocked against opening when the amount of cement in the hopper is underweight by more than one percent or overweight by more than three percent of the amount specified. Cement and aggregate batchers must be interlocked against cycling a new batch until all weigh hoppers are empty, the scale at zero, and the discharge gate closed.

It is also required that all scales be "sealed," which means that they must check within 0.2 percent of a test weight for any single static weighing.

It can be seen that in the present practice there are many different interrelated tolerances and operating accuracies specified. Some are consistent with equipment capabilities and reasonable product quality and others are questionable. This is a part of the overall problem.

More specifically, the primary problem area centers around the fact that it is one thing to state an operating tolerance and another thing to be assured of getting it. When there is manual operation the human error, either accidental or intentional, is added to the mechanical tolerance. There is no way to check either during production except by close observation or by broad comparisons against accumulated output quantities.

It might appear at first glance that mechanical interlocks would provide assurance. However, these complicate the plant mechanism and are subject to mechanical failure and being overriden. It would be impossible to operate a plant with a system of interlocks which could not be overriden. And this factor reintroduces the possibility of manipulation.

There is little ordinary incentive for a contractor to shortcut the weighing operations except for the purpose of keeping up production when one bin is going dry, etc., or to deliberately short an expensive item like cement. Generally speaking, the contractor's and engineer's interests are the same--demonstrably efficient, uniform specification requirements. How to encourage and assure this is the basic reason for this study.

As in any problem of control, it is desirable to think in terms of direct measurement of end result rather than imposition of mechanical limitations and methods on the producer. There is also the very real fact that plant size, type, and method of operation varies widely throughout the State. They range from highly automated, complex installations in major metropolitan areas to portable plants for production from local material sources and to the type of plant established in small out-of-the-way communities for relatively low quantity intermittent commercial work.

All these types of plants, if in good condition and operated properly, can give good results. What is desired is some means of knowing exactly what amounts of material are actually weighed over the various plant scales for each cycle of operation without the necessity of requiring major mechanical modification of the plant, other than that which may be necessary to put it in proper working condition, and without introducing unreasonable delay in the batching cycle.

This sounds very much like some form of monitoring and recordation that can be a part either of the permanent installation or temporarily installed for the duration of a given project.

New York State is an acknowledged pioneer in requiring recordation as a specification matter. However, to our knowledge, this has been restricted to requiring built-in capabilities. This means that the plant owner must rebuild his plant if necessary. The essential difference for purposes of this study is that the recordation system should be capable of functioning in conjunction with the normal method of plant operation, whether manual or automatic, and that any required mechanism be of such nature that it could be made available on a loan or rental basis and capable of being transferred from plant to plant without unreasonable effort or expense.

PART ONE

of

A FINAL REPORT ON

"RECORDATION OF QUANTITIES OF MATERIALS

INCORPORATED IN

BASE AND PAVEMENT PLANT MIXTURES"

C. Report by Norman Pitt, Incorporated

STATE OF CALIFORNIA

DIVISION OF HIGHWAYS

"RECORDATION OF QUANTITIES OF MATERIALS INCORPORATED IN BASE AND PAVEMENT PLANT MIXTURES"

BY: NORMAN PITT, INC.
8696 Atlantic Avenue
South Gate, California
July 15, 1968

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

This report was prepared in cooperation with State of California, Transportation Agency, Department of Public Works, Division of Highways,

and

U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

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I CONCLUSIONS

1. It is possible within the present "state-of-the-art" to introduce four load cells and related equipment which will record independently what is taking place in a plant batching PCC, AC, and CTB.

2. The introduction of these load cells will not interfere with existing operations, manual or automatic.

3. The use of four load cells in the manner described in the report not only makes it possible to record independently, but to weigh independently. Hence, the system is independent of any errors introduced by scale irons which strike obstructions or are tampered with, either accidently or deliberately.

4. The system would be composed of standard items. A multiplicity of read out options exist.

5. The test data indicates the accuracy of the system. It is likely that the Department of Weights and Measures would have to amend the code in some way to make these new techniques fall within the scope of the code.

6. The system should find favor with operators.

7. Further work is indicated.

II CONTRACTUAL REQUIREMENTS AND SCOPE

Contract Paragraph	Recapitulation of Work	Report Section
I.A	The subject study titled "Recordation of Quantities of Materials Incorporated in Base and Pavement Plant Mixtures" was performed as follows: Principal Investigator: Norman Pitt Assistant Investigator: Ugo Racheli	
I.B.1.	The study demonstrates the feasibility of automatic recordation of data as requested (see also Paragraph I.B.5. added by the First Supplement dated August 2, 1967) for both existing and new plants.	XI
I.B.2.	The Contractor met with the representatives of the Division of Highways at the following times: November, 1967 - Mr. Spickelmire June, 1968, Mr. Spickelmire July 10, 1968 (Test) - Mr. Spickelmire	
I.B.2a.	Capability of being approved by the State Bureau of Weights and Measures.	X
I.B.2b.	Adaptability to plants regardless of type. During the course of the study plants were segregated into two general types:	
	a. Plants batching ingredients by weight	IV
	b. Continuous plants measuring ingredients volumetrically.	XII
	The first type has been analyzed in great detail and most of the discussions contained in the report pertain to gravimetric batching plants. Volumetric continuous plants have been considered separately in Section XII of the report.	

I.B.2c.	Accuracy of the recording system has been analyzed by calibration of equipment under test and comparison with accepted standards.	X
I.B.2d.	Dual capability of operation and randomization have been examined in detail. Awareness of the operator while randomizing the operation is a factor in the selection of the equipment.	XI
I.B.2e.	Identification of recorded operations.	V
I.B.2f.	Capability of being installed remotely with limited access.	V
I.B.2g.	Availability of equipment.	V
I.B.2h.	Cost of the equipment.	XI
I.B.3.	Survey of basic equipment suppliers and manufacturers. Recordation devices presently available or under development were designed to meet the specifications of the State of New York and Michigan. They satisfy most requirements except randomization and inspection of data generated. Problems encountered in the introduction of an independent system are analyzed in the body of the report and in Section XI.	VI
I.B.5.	Added by First Amendment dated August 2, 1967.	VII
I.C.	Interim report dated December 27, 1967. Final report dated July 15, 1968.	

III BACKGROUND

The post-award conference was held in Sacramento on September 20, 1967 and attended by Mssrs. John Obermuller and Leigh Spickelmire of the Division of Highways and Mssrs. Norman Pitt (Principal Investigator) and Ugo Racheli (Assistant Investigator) of Norman Pitt, Inc. It was decided that three general areas had to be investigated in order to satisfy fully the requirements of the contract:

1. Mode of Data Generation and Recordation

2. Equipment Review and Selection

3. Comments from Manufacturers and Operators

Later Item 4 was added as follows:

4. Test of Most Promising Equipment

IV MODE OF DATA GENERATION AND RECORDATION

The study basically was intended to develop whether or not an independent method of monitoring and recording could be installed, irrespective of whether the plant used a dial head, a beam, was operated automatically, or manually, batched concrete, hot mix or any other solid and liquid materials, was modern or old, installed in a major metropolis or in a remote area.

Based on this, for instance, comparing actual scale readings with batch requirements by a photographic method of recording, i.e. by taking pictures of the dial heads at the proper times, was ruled out because any inaccuracy of the existing system would remain undetected. Other considerations, such as maintaining proper ambient conditions, could be overcome but the system was hardly explored because of the problem mentioned above.

Load cells were selected for incorporation in the existing scale system as the cleanest method of obtaining a separately recordable signal.

A transducer, linear or angular, mounted in the existing dial heads was considered but rejected primarily because it is an expensive modification for a manual plant and would not detect any inaccuracy in the existing lever system, intentional or accidental.

Similarly, a single load cell in the draft rod leading to the existing dials, while representing the simplest and most economical method, would not detect any inaccuracy of the existing lever system.

Four load cells in the tie rods between the hopper and the scale main levers give an accurate load signal totally independent of any inaccuracy of the existing scales due to friction, wear, dirt or tampering.

Having decided on load cells to generate a signal we explored digital versus graphic recording of the signal. Pen type graphic recorders introduced the possibility of quantitative interpretation and the virtual impossibility of obtaining a pay ticket without introducing a digital device. Digital recording appeared practical and seemed to have no disadvantage.

At the beginning of the program, then, while keeping an open mind for any recordation system, it was visualized that an instrumentation package consisting of four load cells, a totalizing and control unit and a digital printer would come the closest to satisfy all the feasibility criteria defined in the contract.

V EQUIPMENT REVIEW AND SELECTION

Since it was essential that the program use instrumentation within the existing "state-of-the-art" one must state that the selection outlined above did take into consideration past experience by the investigators, operators, and manufacturers of automatic batching equipment.

Indeed, several meetings with manufacturers of automatic weighing equipment bore out the fact that systems were in existance which detected weight by means of load cells; the total output was then fed into a control unit which would perform automatically several operations and finally print out a record (sometimes a very sophisticated one) of all weights and operations performed.

Several manufacturers mentioned that they had entered the field of automatic batching systems for highway construction materials because of the requirements introduced in the State of New York.

All manufacturers indicated that load cells were used extensively on in-plant batching systems but they had never been used on road machinery because of difficulties in obtaining approval from government agencies, especially the Bureau of Weights and Measures. Since all batching plants for road building materials have mechanical lever systems with dials (or beams), the general approach was to generate an electrical signal by introducing a transducer (angular or linear) in the dial housing and proceeding as indicated above with control and recordation.

In answer to our queries, all batching equipment manufacturers indicated that the method of generation of the signal is immaterial to the functioning of the recordation unit, but load cells had just never been used on road equipment.

In our search of a "state-of-the-art" in application of load cells, we found that load cells have been used frequently, if not extensively, in Europe and were producing very satisfactory materials even though we couldn't ascertain whether or not it met Bureau of Weights and Measures tolerances on weighing accuracy.

Having decided that load cells were within the "state-of-the-art" but that our approach of introducing the load cells to generate a signal independently of scale levers was unusual, it became necessary to decide on a type of plant to try the equipment.

In order for the system to receive a most intense workout, it was decided to use a hot mix plant rather than a concrete batch plant since the hot mix plant batches under less favorable conditions. It was also essential to install the system in such a way as to not interfere with any existing system.

Anybody who has observed a good manual operator at work has had the impression that "the needle never stops". Even discounting intentional cheating where the next bin has started to flow before the previous has stopped, it is general and well justified practice to get the hopper full in the least time, thus reserving any time left in the batching cycle for other operations to be performed (feed control, temperature control, etc.). Thus, the good operator quickly learns the time interval necessary to compensate for mid-air material and will cut material flow at the proper time and start feeding the next without a definite stop in the motion of the scale needle.

Automatic batching systems have built in devices to compensate for mid-air material to achieve the same high speed batching.

Plotting out graphically the position of the scale needle (which is the analog of the actual weight in the hopper if we discount rebound of the scale system due to mechanical inertia) versus time we obtain a well defined profile.

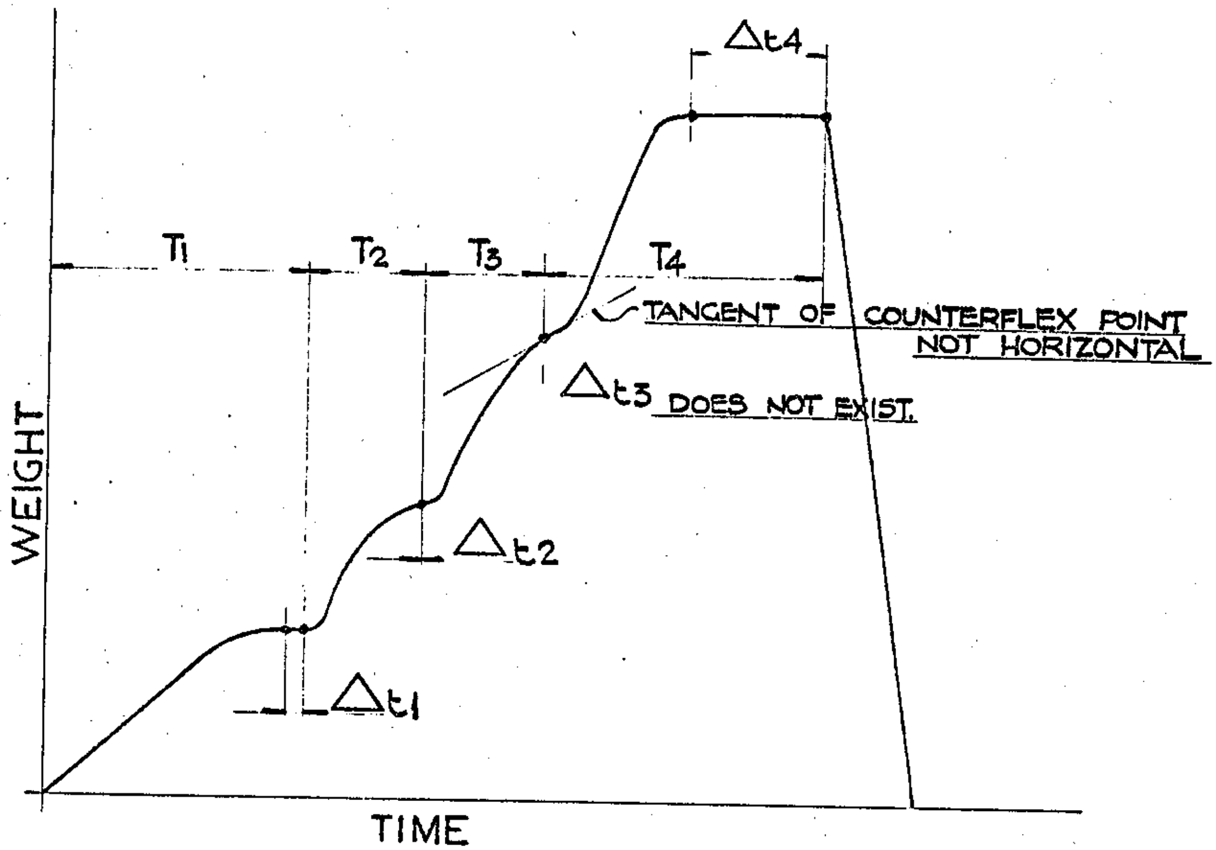


FIG. I. CYCLE DIAGRAM

The value to be recorded, if it is to be significant, must be taken when the tangent of the curve is horizontal at the counterflex point; at the same time any Δt_i is unproductive time as explained above and must be kept at a minimum. At the limit even a zero Δt_i, provided it exists, corresponds to a significant value of weight and is recordable.

It is possible to devise an instrument which detects motion (or electrical current flow) and records only those values where a Δt_i exists; indeed the instrument eventually tested did have such a device and it was run with the device inoperative for a period of time to compare performance.

Is Δt_i or even T_i large enough to allow the printer to record the W_i values at each point of flex? At first it was felt that mechanical printers (printers, that is, where the translation from electrical current magnitude to digital weight output is performed mechanically) might be too slow and would force us to either face an impossible task or introduce by means of electrical interlocs an objectionably large delay at each Δt_i.

Attention was then shifted to electronic equipment and here this problem appears to be minimal. Since the value of W is monitored continuously and instantaneously, it can be read at any time by generating a signal such as pushing or releasing a push button or closing the contacts of a limit switch on a gate. The value of W can be stored with the proper identifying signal in a memory core only if and when the rate of change of W becomes null; finally it can be translated into digital form and printed with the identifying data at the particular speed of the printer selected. The same encoder would also feed to the printer other data such as date, type of mix, mix number, etc. in the proper sequence.

However, a new problem is introduced because the weights are cumulative for each ingredient so that given W_1, W_2, W_3, W_4, and T_0 as the individual weights of the ingredients and the balance left in the hopper after discharge, the printout would show

$$W_{T_1} = T_0 + W_1$$

$$W_{T_2} = T_0 + W_1 + W_2$$

$$W_{T_3} = T_0 + W_1 + W_2 + W_3$$

$$W_{T_4} = T_0 + W_1 + W_2 + W_3 + W_4$$

The actual total weight should be $W_4 = W_{T_4} - T_0$ and likewise any individual ingredient weight should be:

$$W_i = W_{T_i} - W_{i-1} - \cdots - W_1 - T_0 \text{ or } W_i = W_{T_i} - W_{T_{i-1}}$$

If the individual weights must be printed as well as the actual total weight then a computer, albeit a very simple one, must be introduced to perform the operations indicated above. Indeed this seems to be the requirements of the State of Michigan with regard to recordation of weights on batching plants contracted to furnish materials on State jobs. The specifications of the State of New York stop at the point where computers are not actually required.

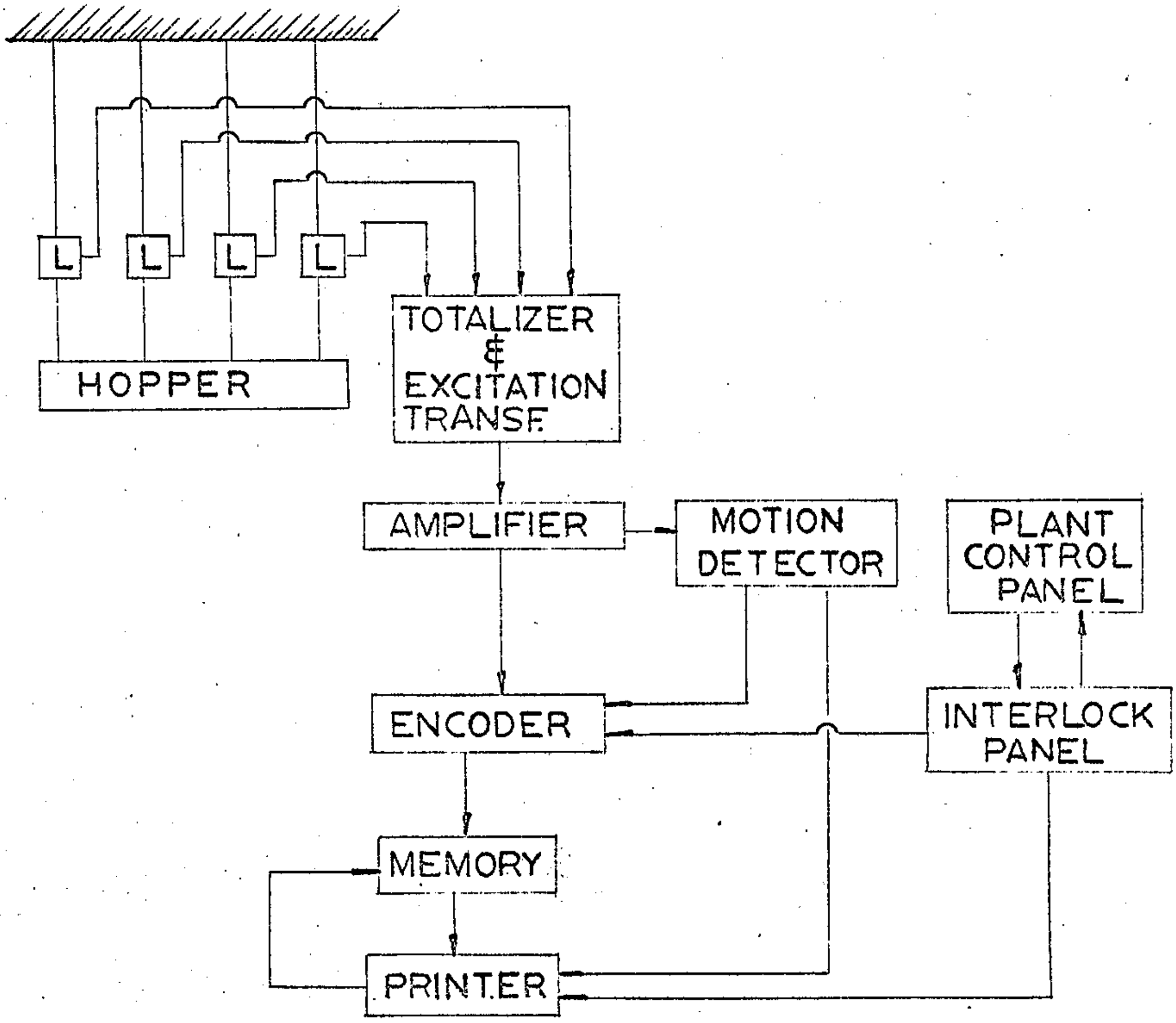


FIG. 2. FUNCTIONAL DIAGRAM

Printers, of course, can be purchased with an almost endless number of optional features such as a keyboard for entering any kind of information pertaining to a batch, a manual adding machine; also the format of the output can be obtained in a number of ways such as punched or printed cards, punched or printed tapes, magnetic tapes. The final selection of output format would have to be decided taking in consideration the intended use of the data recorded and what further processing it must be subjected to. At this point it appears that a printed tape would give a compact package, reasonably easy to interpret visually and easy to translate into a deck of IBM cards for computer processing. A direct card puncher has the following disadvantages: high cost, delicate components easily damaged by handling and dust, large bulk including automatic card feed and storage, difficulty in visually interpreting cards.

A magnetic tape is totally uninterpretable visually but otherwise is the most compact and most rugged recorder available.

VI COMMENTS FROM MANUFACTURERS AND OPERATORS

Comments from manufacturers and operators were solicited immediately after the post-award conference by means of similar letters sent to all prominent companies in the field. Three broad classes of companies were contacted:

1. Manufacturers of Weighing Systems
2. Manufacturers of Plants for Production of Road Building Materials
3. Operators of Plants for Production of Road Building Materials

Manufacturers of Weighing Systems

The response was generally positive showing great interest in the scope of the subject study.

Most manufacturers have geared up to produce systems acceptable in the State of New York. These systems are becoming the optimal standards, so to speak, and generally consist of a mechanical lever system (more or less enclosed), a standard indicating dial with transducers to convert the position of the needle to an electrical output. This output amplified in conjunction with other signals and interlocks is used to control automatically all batching operations. Finally the output is coded in digital form and printed.

Most manufacturers indicated that the electronic sophistication of the systems was increasing and the printing had to be controlled through a device such as the Giannini Shaft Encoder which acts as an electronic encoder and memory unit. This is made necessary by the slow speed of the mechanical printers. An exception to this trend was the response of the Howe-Richardson Scale Company which offered the Magna-Tronic system (see "Equipment Review" and "Testing" paragraphs).

In general weighing systems manufacturers had never approached the task of recording the batching data without also performing automatic control functions on batching plants; the specifications introduced by the State of Michigan were generally leading in the direction of recordation only but were not finalized to the point of giving a sure indication of the ultimate requirements.

As to the use of load cells on batching plants, there is a general consensus that the job could be done but has never been tried since the mechanical levers are reasonably inexpensive and not unfamiliar to the personnel of the various State Bureaus of Weights and Measures.

All manufacturers contacted stated that they could furnish a system which uses the output of the dial head transducer, an electronic amplifier with an encoder and memory unit and a printer such as those manufactured by NCR or Clary. The above system obviously cannot detect any inaccuracy generated in the lever system; these inaccuracies can be considerable and increasingly so when the weight approaches the total hopper capacity which is the most significant value for determining pay data.

Finally, there is a widespread impression that County and State personnel are generally against the use of load cells and therefore their sale to batching plant or scale manufacturers had not been promoted to any degree.

Batching Plants Manufacturers

Plant manufacturers in general expressed the opinion, or fear, that more and more States would adopt different specifications, thus forcing them to tailor make plants for operation in a specific State. Most contracts now impose the burden on the plant manufacturer to guarantee that the plant meets all specifications for batching control in addition to all other requirements for air pollution, material temperature, gradation, etc.

Some requirements force the plant manufacturer to change substantially the design of certain components of the plant and add considerably to the initial and maintenance cost of the plant and to the cost of initial start-up assistance.

The added cost of meeting New York specifications was quoted as being between $12,000 and $30,000 for a medium sized asphalt batching plant.

The effort of the State of California to keep in touch with industry and to study the problems connected with control of automation and recordation was welcomed.

After the scope of the study was clearly defined, manufacturers did comment on various matters even beyond the outline of our letters.

However, it seems obvious that they believe the State's interests will not coincide with their interests and something restrictive may result. Obvious questions were raised, such as:

1. The applicability of recordation to manual or semi-automatic plants.
2. Dual systems of weight generation and resolution of discrepancies between the two systems.
3. Projected savings in inspection personnel.
4. Final use of the data recorded.

In general the comments received indicated that manufacturers feel the operators of manual plants would be penalized if required to add recordation to their plants at their expense because of the necessity to add interlocks, limit switches and to upgrade their gate mechanisms. Operators of automatic plants already have most of the above work behind them.

In the case of dual systems installed by the State one continuing question was that in the case of a discrepancy it would be hard to settle the question of which system was in error unless the control system were exceedingly reliable.

Most manufacturers feel that there would be little saving of inspection personnel but that automating the recordation would free the inspector to perform other more valuable functions and thus improve the quality of the materials produced.

The final use of the data was discussed to the extent that elimination of a truck scale might be generally advantageous and certainly the ability to analyze a large number of batches through electrodata processing machine would contribute substantially to any statistical study of road building materials and their production.

Batching Plants Operators

Batching plant operators were very receptive to any idea that would reduce the cost of calibration of their weighing systems, speed up the generation and handling of pay-weight data and help them produce materials acceptable to the State.

In general they showed great interest in the use of load cells to calibrate mechanical lever systems through full range, a job which is expensive and even dangerous to do by hanging weights to the hoppers.

Some concern was expressed as to the effect on production of any delay caused by the printer; this, of course, has been always considered and thoroughly analyzed during the test.

VII SELECTION OF ACTUAL EQUIPMENT AND INSTALLATION

As indicated in Section V, theoretical considerations mitigated in favor of a completely electronic system. However, Howe-Richardson Scale Company offered a "Magna-Tronic" weighing system. This system uses load cells to generate an electric signal, but converts the signal to a digital output by means of a mechanical device.

It was their feeling that this device is more rugged, less expensive, less sophisticated, and, if satisfactory, would be totally reliable over a very long period. The question, of course, was the speed of response. After some discussion, we accepted their offer and installed such a system.

As it turned out, it was an excellent recommendation and met the requirements exceedingly well.

The equipment was installed on a Madsen 6000# A.C. batching plant operated by Industrial Asphalt Company in Clairmont, California. Four brackets were welded to the aggregate weigh hopper and the load cells installed at the four corners between the main torque levers and the new brackets. The position of the weigh hopper is thus virtually unchanged and no other mechanical modifications were required. On many plants, where the scale rods are sufficiently long, no mechanized modification would be required for installation of the load cells.

The load cell cables were run to a junction box mounted on a beam at the back of the plant and a single output cable was run in a shielded conduit to the Magna-Tronic cabinet.

The "Magna-Tronic", an "off the shelf" item with Howe-Richardson Company, was installed in a room adjacent to and at the same level as the operator's platform. A relay box for the printer energizing circuit was installed on the operator's platform.

The M-R Printer is standard except for the energizing circuit which was interlocked with the plant controls to obtain an automatic command signal for printing.

The function of the relay box is as follows: When any bin gate solenoid is de-energized, the printing cycle is started and a timer is energized. The timer disables all bin gate solenoids and the hopper discharge gate solenoid for approximately 1-1/2 seconds. This time delay is necessary in order to insure that the printing cycle is started only when the dial needle and the coaxial printer star wheel come to rest.

The printer used for the test was the simplest available. The ticket was advanced manually and no identification of ingredients was made by the printer. A tape printer with automatic advancement and identification of ingredients, batch number and date is also available.

EQUIPMENT LIST

a. LOAD CELLS - Revere Corporation of America
Wallingford, Conn.

Revere USP 2500

Excitation	15 Volt AC
Rated Output	3.000 $\pm$ .1% MU/volt of excitation
Non Linearity	.05% of rated output
Repeatability	.02% of rated output
Creep	.03% of rated output in 20 minutes
Temp. Effect on rated output (15°F. to 115°F.)	$\pm$.0013%/°F of rated output
Overload Rating (Safe)	150% of rated capacity
Material	Stainless Steel

b. CONTROL UNIT - Howe-Richardson Scale Co.
Rutland, Vermont

Howe-Richardson Magna-Tronic Dial, Model 7700

Chart Graduation - 6000# x 5#
Zero Adjust Control
Lock Out Switch Control
Check Weight Control
Hold Weight Control
Tare Control

c. PRINTER - Howe-Richardson Scale Co.
Rutland, Vermont

Howe-Richardson M-R Printer, Ticket Recorder Type

VIII PERFORMANCE OF THE TEST

Having surveyed the field for equipment, and having concluded that a system with four load cells as the primary sensing device should do everything called for and a little more, and having obtained the use of a sensing system complete with dial and printout, it now became possible to focus on what form the test should take.

It was decided to monitor a hot mix plant because it would be more severe service than other plants. It was decided to monitor an automatic plant, but at least partly because existing automatic plants are touchy and we did not wish to become embroiled in a discussion as to whether anything we were doing was causing the automatic system to malfunction, we ran manually during the final test.

The format of the test was simply this. We would install our gear and record whatever the plant produced. We would photograph the plant dial head and compare it with our card records. We would compare the total weights with the truck weights. Both systems would be calibrated prior to running.

The final test was conducted on July 10, 1968. Prior to the test both weighing systems had been checked out thoroughly and were in satisfactory working condition.

Both weighing systems were calibrated simultaneously by a licensed contractor through the total range, that is, to 6000 pounds, and found to operate within the tolerance range set by the Bureau of Weights and Measures.

A photographer had been contracted to take time-lapse motion pictures of the plant aggregate dial during the test. Ten frame sequences of the position of the needle on the plant dial were taken for each ingredient weighed throughout the test.

The test started at approximately 8:30 AM and 80 batches were recorded with one numbered card being printed for each batch. In the afternoon an additional 70 batches were recorded and three truck loads were calculated by adding to the weight shown on the cards the weight of the asphalt used in each batch. At the same time the trucks were weighed empty and after receiving the material from the plant. The truck scale was not calibrated for the test but had been checked out and care was taken to stop the trucks in the same position every time to minimize variations encountered on that type of platform scale.

Soon after the beginning of the test it was noticed that the third ingredient weight was not being printed. Analysis of the batching cycle indicated that the motion of the needle during loading of the third ingredient was very rapid and of short duration so that the test instrument didn't have enough time to print the second ingredient and catch up with the plant scale for the next printout. To overcome this difficulty the motion detector relay was isolated and the batches were recorded. All ingredients were now being recorded but the values found incorrect because the recorder would print the value of the weight at the instant the operator depressed each gate push-button. The motion detector relay was reconnected and the timer adjusted to approximately three seconds. All weights were now being recorded accurately with some exception where double printing of one ingredient occurred. The total weight was always printed accurately.

The load cells performed flawlessly throughout the test. Note that to equalize the load on the cells it is only necessary to connect them in pairs and tighten the rod nuts until one gets a close value on the dial for both pairs.

The dial needle tracked the weight very well and vibrations of the needle can be dampened electronically by adjusting the amplifier gain control thus producing a motion smooth and easy to read.

No stabilization of the hopper was found necessary even though severe horizontal vibrations occurred when gates were being opened or closed.

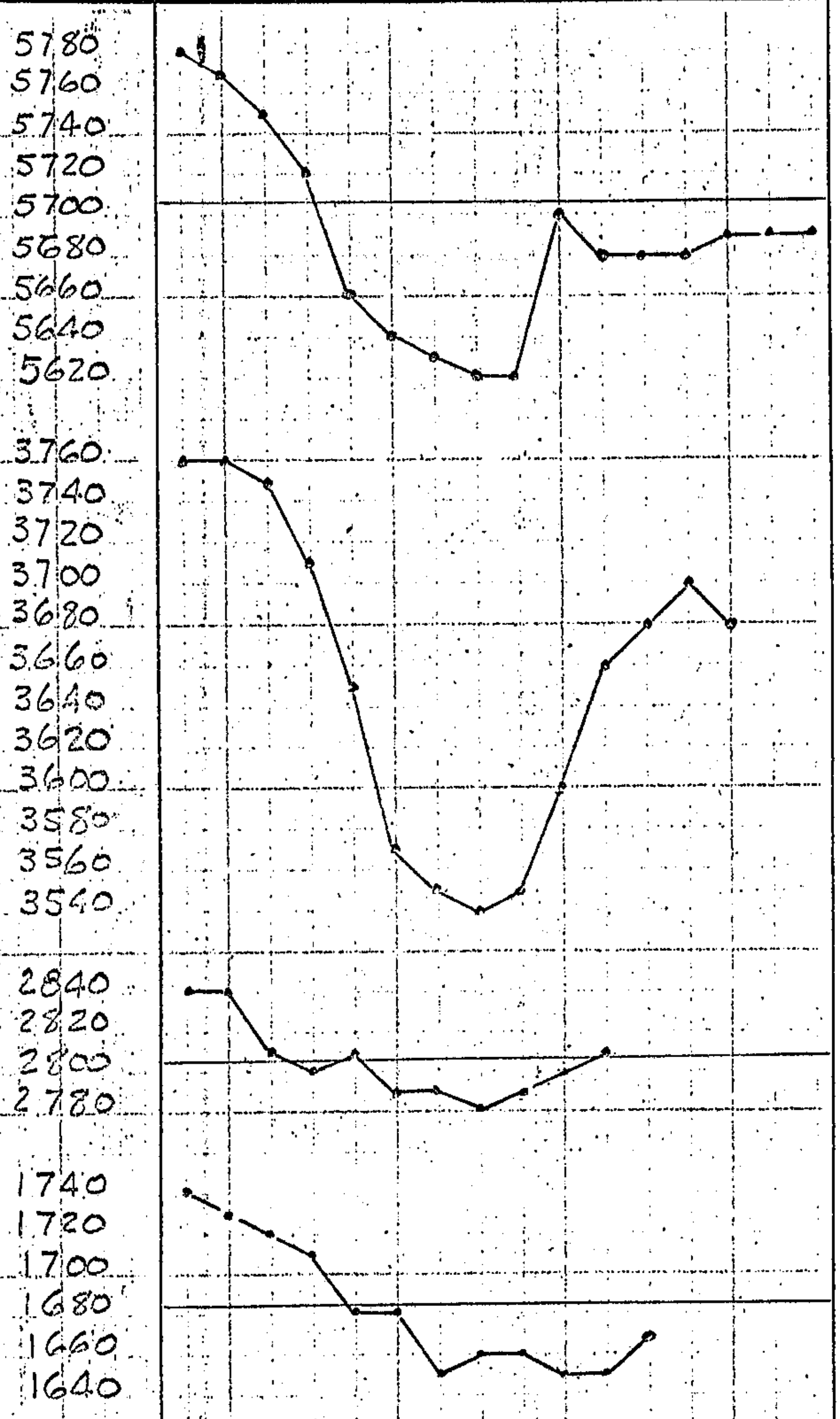
The printer gave a highly legible record.

The interlock system devised for the test didn't allow us to achieve the best cycle time as discussed in paragraph 4. The difficulty was that where it was felt that one timer would be sufficient to allow for the start of the printing cycle for all ingredients, individual timers are required to achieve the best cycle time. There is no problem anticipated in designing a control box that would perform the task indicated above.

IX TEST DATA

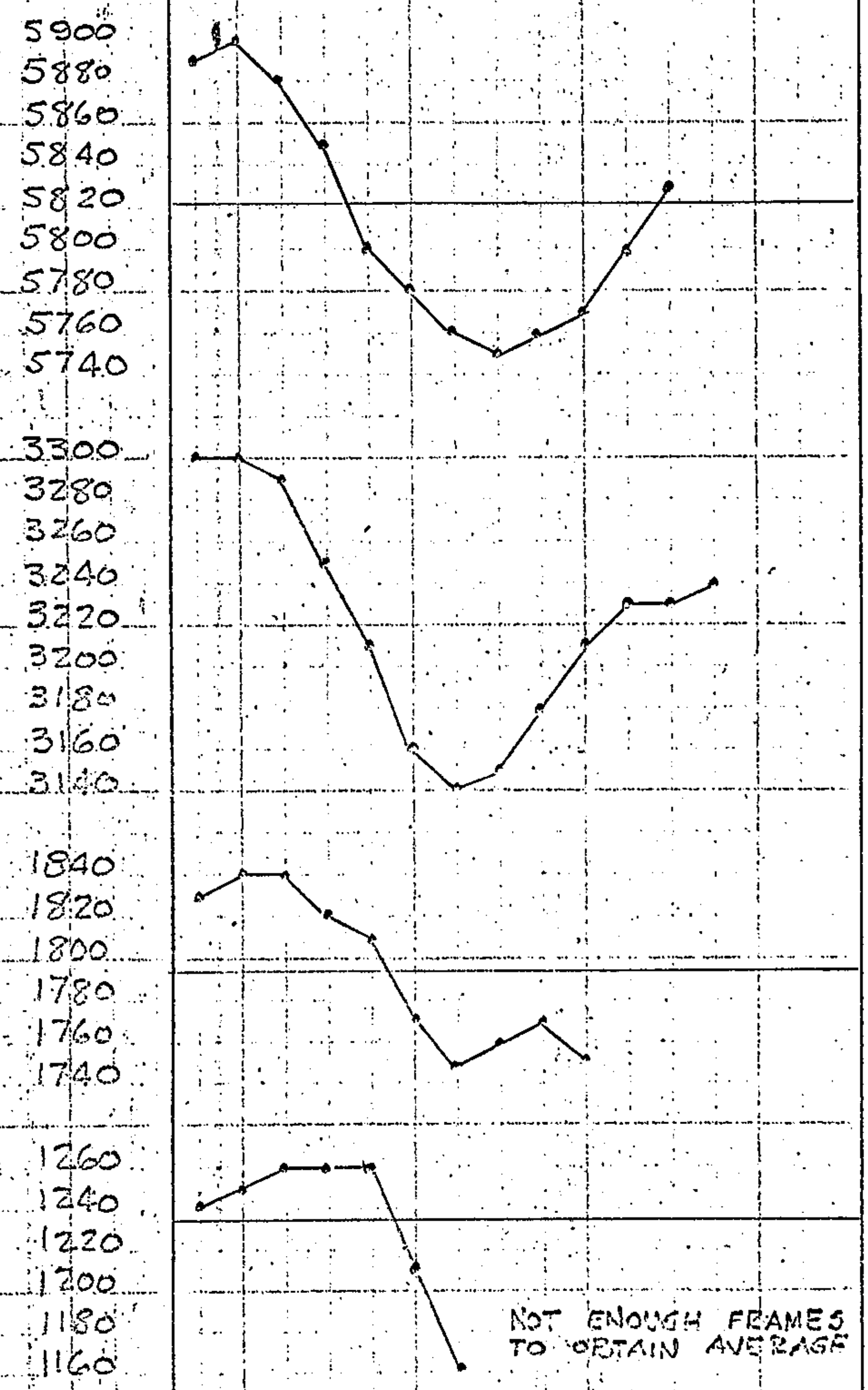
BATCH NO. 101

SCALE WEIGHT	PHOTOGRAPHIC RECORD	MATH. AVERAGE	PRINTED WEIGHT
5780–5620		5705	5700
3760–3540			
2840–2780		2805	2820
1740–1640		1683	1660



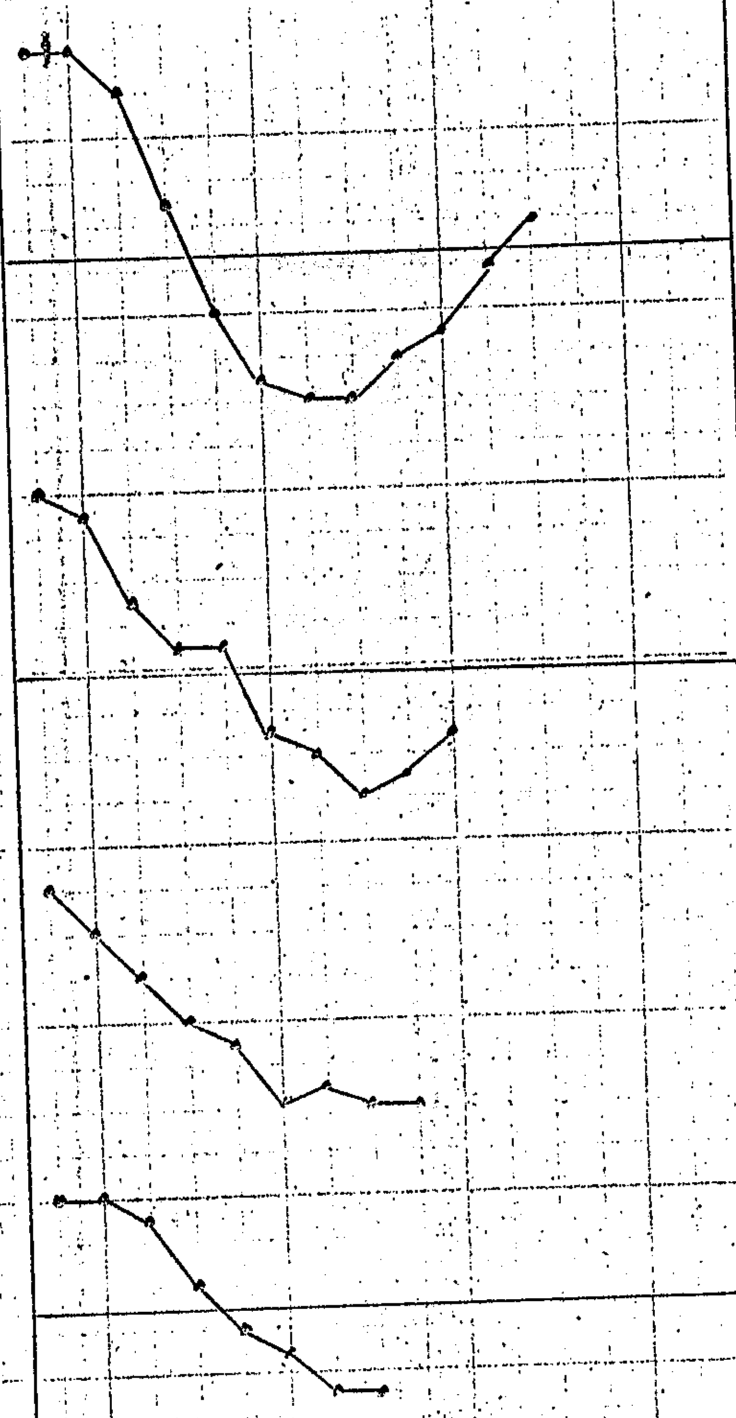
BATCH NO. 102

SCALE WEIGHT	PHOTOGRAPHIC RECORD	MATH. AVERAGE	PRINTED WEIGHT



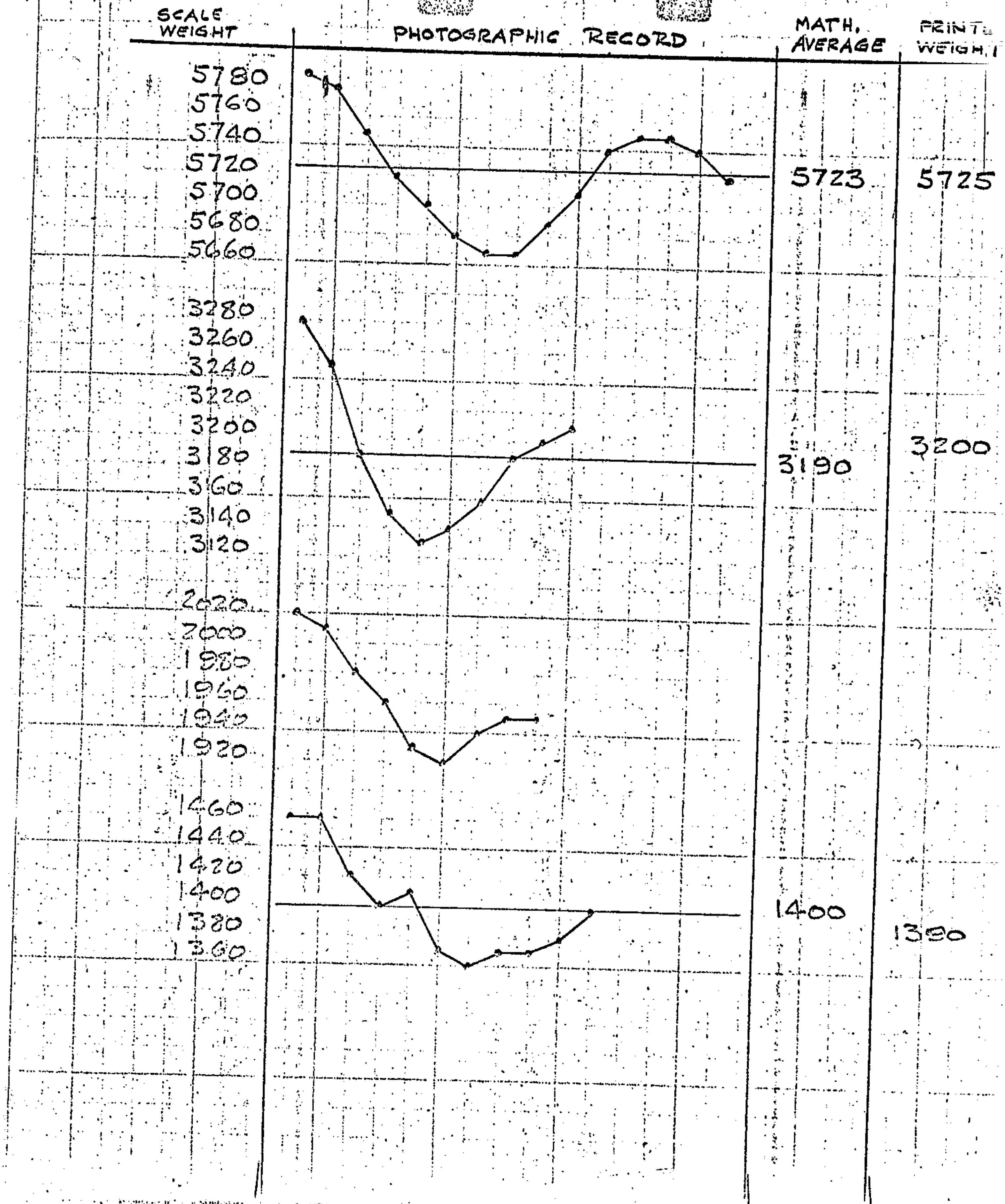
Scale weight range	MATH. AVERAGE	PRINTED WEIGHT
5900–5740	5821	5820
3300–3140		
1840–1740	1794	1790
1260–1160	1234	1210

BATCH NO. 103

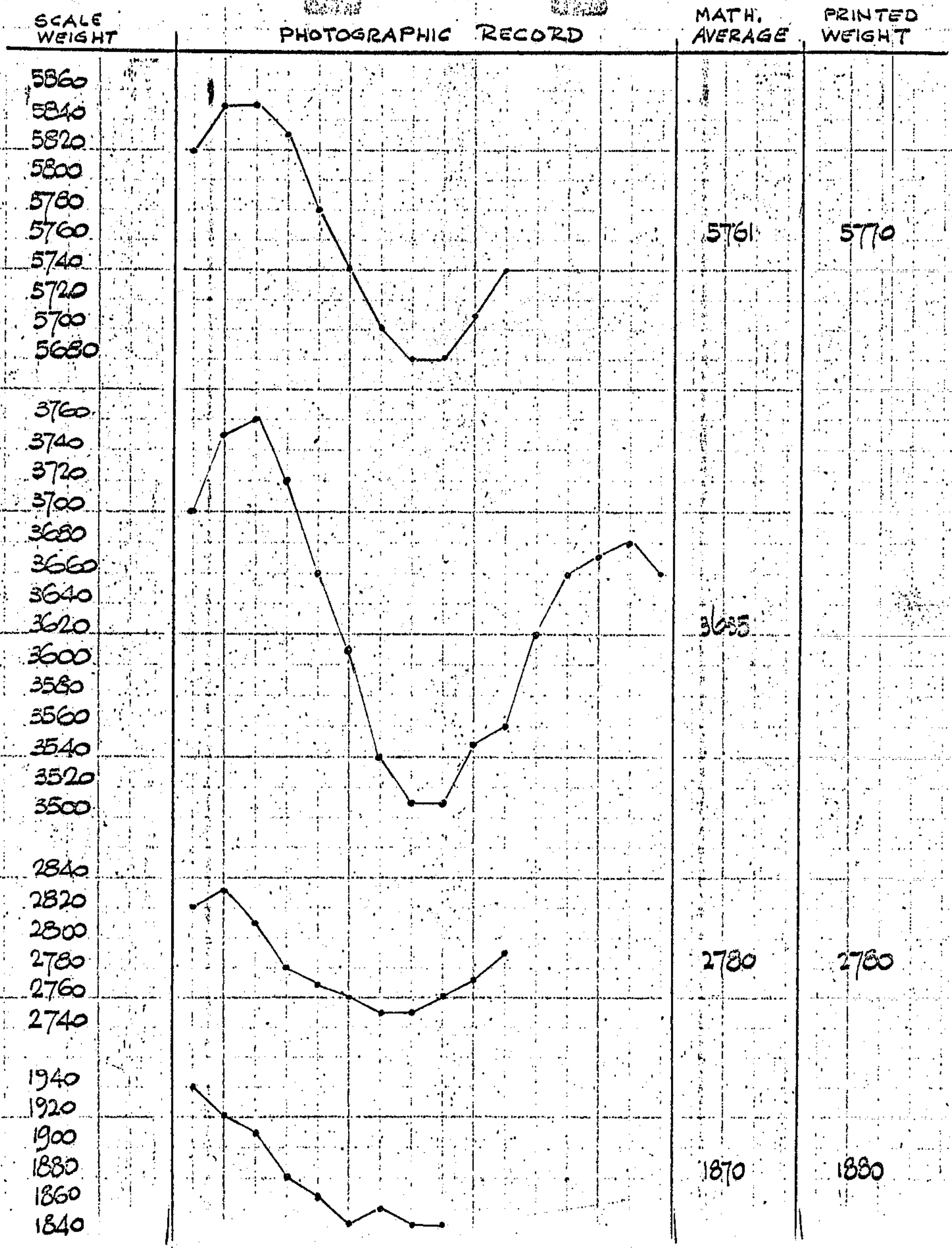


SCALE WEIGHT	PHOTOGRAPHIC RECORD	MATH. AVERAGE	PRINTED WEIGHT
5920 5900 5880 5860 5840 5820 5800 5780 5760		5825	5825
3300 3280 3260 3240 3220 3200 3180 3160		3219	3220
1920 1900 1880 1860 1840 1820			
1320 1300 1280 1260 1240 1220		1270	1260

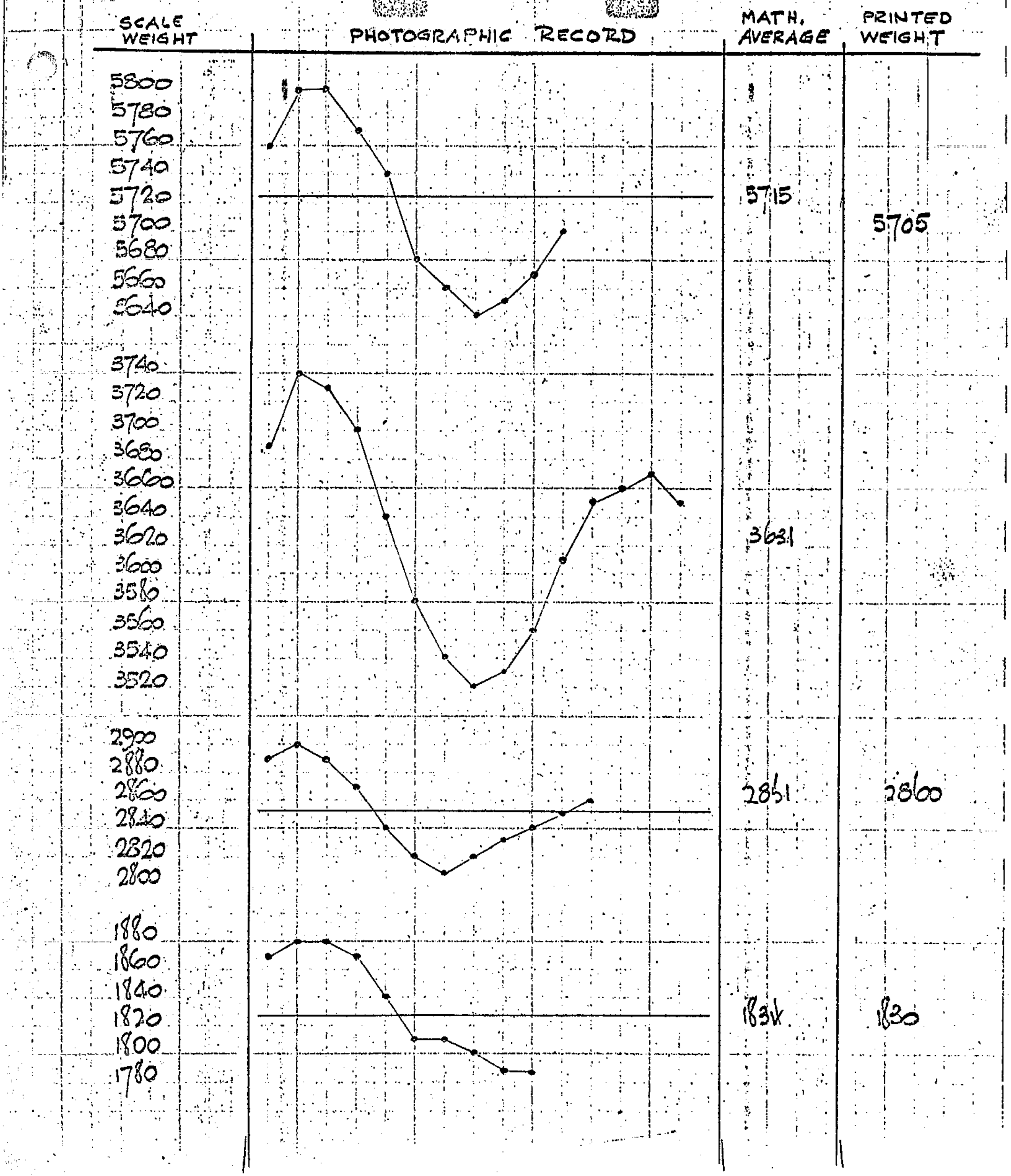
BATCH NO. 104

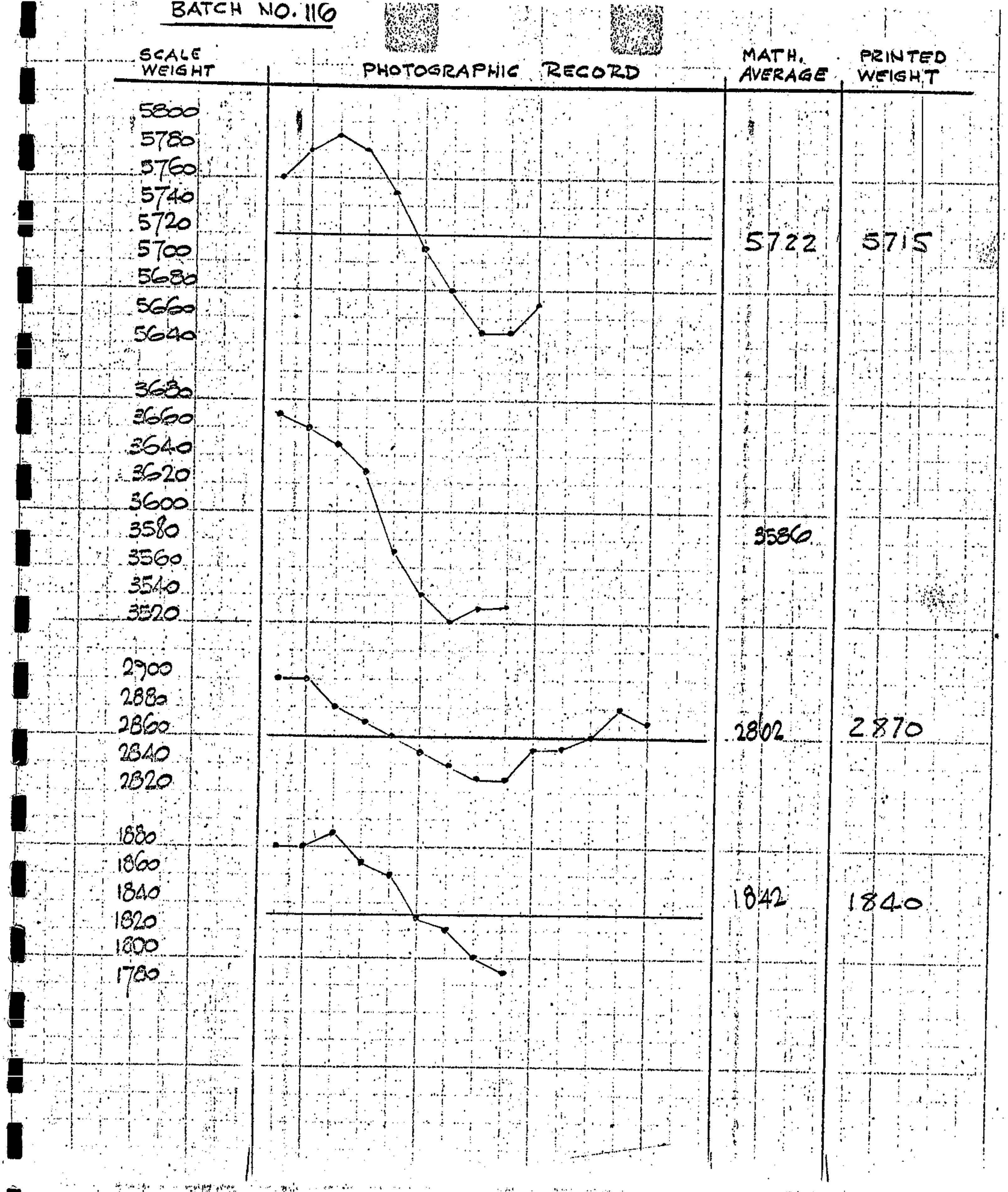

SCALE WEIGHT
PHOTOGRAPHIC RECORD
MATH. AVERAGE
PRINT WEIGHT
5780
5760
5740
5720
5700
5680
5660
5723
5725
3280
3260
3240
3220
3200
3180
3160
3140
3120
3190
3200
2020
2000
1980
1960
1940
1920
1460
1440
1420
1400
1380
1360
1400
1390

BATCH NO. 11a

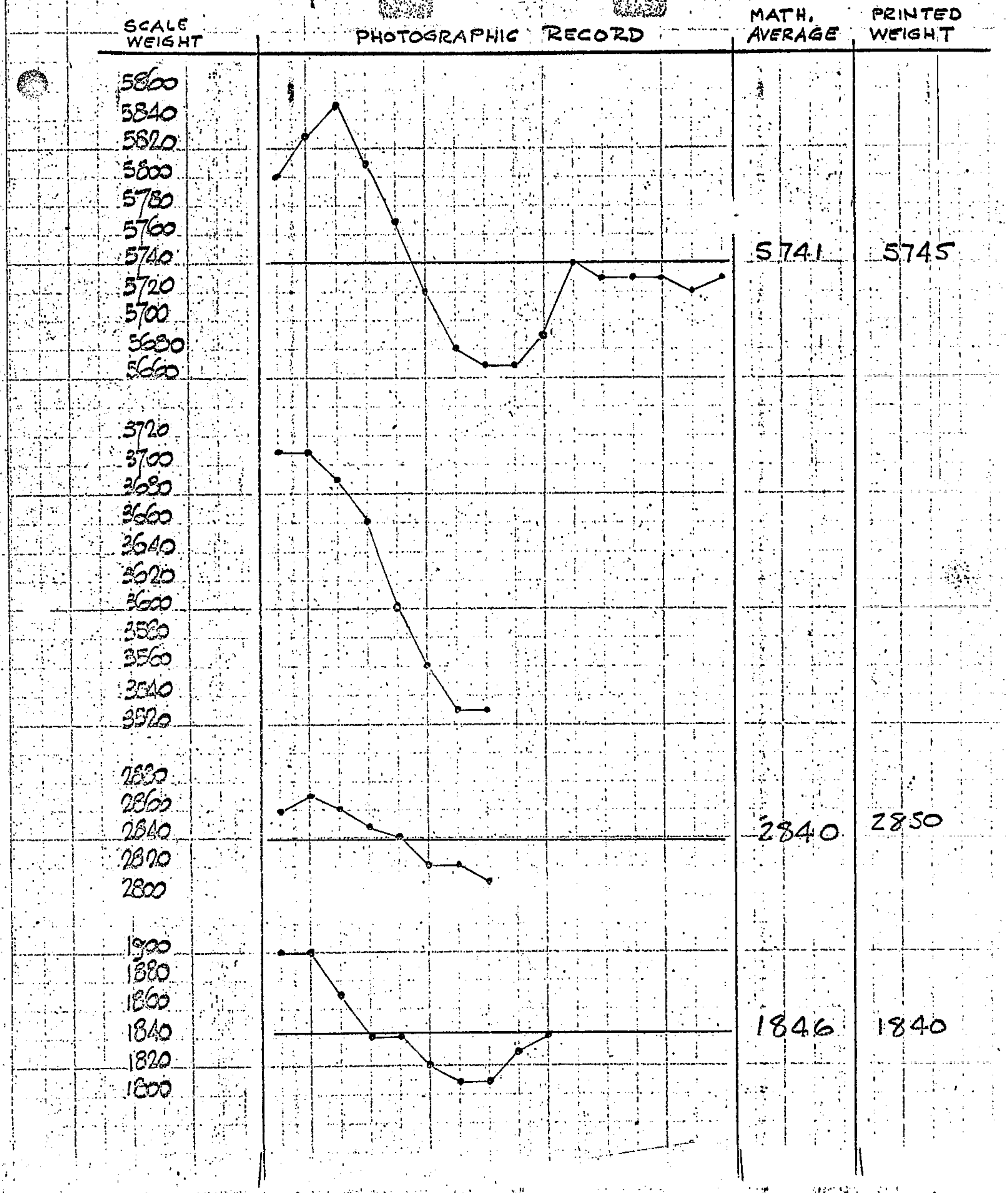

SCALE WEIGHT
PHOTOGRAPHIC RECORD
MATH. AVERAGE
PRINTED WEIGHT
5860
5840
5820
5800
5780
5760
5740
5720
5700
5680
5761
5770
3760
3740
3720
3700
3680
3660
3640
3620
3600
3580
3560
3540
3520
3500
3685
2840
2820
2800
2780
2760
2740
2780
2780
1940
1920
1900
1880
1860
1840
1870
1880

BATCH NO. 115


SCALE WEIGHT
PHOTOGRAPHIC RECORD
MATH. AVERAGE
PRINTED WEIGHT
5800
5780
5760
5740
5720
5700
5680
5660
5640
5715
5705
3740
3720
3700
3680
3660
3640
3620
3600
3580
3560
3540
3520
3631
2900
2880
2860
2840
2820
2800
2851
2860
1880
1860
1840
1820
1800
1780
1834
1830


BATCH NO. 116
SCALE WEIGHT
PHOTOGRAPHIC RECORD
MATH. AVERAGE
PRINTED WEIGHT
5800
5780
5760
5740
5720
5700
5680
5660
5640
5722
5715
3680
3660
3640
3620
3600
3580
3560
3540
3520
3586
2900
2880
2860
2840
2820
2862
2870
1880
1860
1840
1820
1800
1780
1842
1840

BATCH NO. 117


SCALE WEIGHT
PHOTOGRAPHIC RECORD
MATH. AVERAGE
PRINTED WEIGHT
5860
5840
5820
5800
5780
5760
5740
5720
5700
5680
5660
5741
5745
3720
3700
3680
3660
3640
3620
3600
3580
3560
3540
3520
2880
2860
2840
2820
2800
2840
2850
1900
1880
1860
1840
1820
1800
1846
1840

	TRUCK 1	TRUCK 2
ADJUSTED AGG. TOTALS	5620	5765
	5815	5700
	5815	5705
	5720	5735
TOTAL AGG.	22970	22905
TOTAL ASPHALT	1316	1280
	24286	24185
PLATF. WT	− 24200	24040
	+ 86	+ 145
PERCENT	0.3%	0.6%

COMPARISON OF RECORDED WEIGHTS TO TRUCK WEIGHTS

101

5700

5700
2820
1660
0010

101

102

5820
1790
1790
1210
0080

2-324

104

5725
3200
4390
1390
0010

3,24

4-

103

5825
3220
1260
1260
0005

324

3-

SAMPLE OF PRINTOUT CARDS USED FOR TEST

X ANALYSIS OF DATA

The camera was fired manually using as a signal a timer, connected in parallel with the terminal of the relay box. A burst of twelve to fourteen frames was fired every time the signal light came on, covering an interval of time of approximately one second.

A number of cycles were selected for analysis. The indication of the needle on each frame has been plotted in a weight/time graph and exhibits a definite damped sine wave pattern.

The mathematical average of all values on each graph is then compared with the value printed on the Magna-Tronic and has been found to be within fifteen pounds, which represents a .15% accuracy value. Note that the maximum deviation of the existing dial needle is in the order of one hundred pounds or 1.0% and therefore close to the maximum deviation allowed by State specifications.

The accumulated weight of consecutive batches delivered to three tared trucks was compared to the truck scale readout and found to be within +.3%, +.5%, and +.86% respectively. In view of the fact that the truck scale had not been calibrated, the indication is that the value given by the Magna-Tronic is very close and can be brought within acceptable tolerances.

In other words, the load cell system prints a number for the weight which is extremely accurate and extremely fast. If the load cells had been compared to the truck scale in advance and any discrepancy between the two ironed out in advance it seems perfectly reasonable to assume that the record could have been used for payment.

Considering that this was a manual operation and the opening and closing of the gates was performed visually, the discrepancy is extremely small.

XI GENERAL COMMENTS AND RECOMMENDATIONS

The test went very smoothly. The load cells were installed easily. The printer functioned well. A system obviously can be put together which will do what the State of California desires. Independently, it can monitor what a plant is doing, and record it, all without interferring with normal operations.

But the test really opens up the entire question of what is now really happening.

To begin with, the tests and photographs clearly demonstrate that in a good, manual operation, following accepted good practice, even if the scale is properly calibrated, the inertia of the lever system is very large compared to the load cells.

The bounce in the dial when closing the gate is in the order of 20 to 150 pounds, depending on the speed with which material is entering the weigh hopper from the bin above. The accuracy of the scale at rest is not related to the accuracy of the system.

After the gate is closed the operator waits until "equilibrium", which the photographs indicate is really about a 40 pound fluctuation of the needle. Even this is very high compared to the scale accuracy. The percent of error depends on the amount of material being weighed.

In an automatic plant this is compensated for. The system understands that the gate requires closing earlier because of material in the air and requires additional compensation because of impact. This additional compensation is usually partial closing of the gate as the required weight is approached. Therefore, in a conventional automatic plant, if it is carefully calibrated, the system unknowingly is compensating for the inertia in the scales as well as the material in the air.

The load cells have virtually insignificant inertial problems compared to the conventional system of knife edges, levers, rods, etc.

Hence, it seems fair to say that a manual system monitored by this system will show differences in weight and the monitor weights will be a very accurate reflection of what was batched.

An automatic system monitored by this system may read weights and record weights slightly different than the monitor. This has not been tested and should be. But the monitor recordings are in a system of lower inertia and we feel they will be closer to the weight at static equilibrium.

Testing this system against an automatic plant is definitely indicated. This, however, requires a little extra thought and consideration. There is the element of operator relationship. Automatic plants do manfunction and are not well enough understood by the plant operator for him to service. Any malfunction will be blamed on the monitor.

What is really required, therefore, is a test program of modest size which would permit the representatives of the State to focus on one automatic system in one plant. They should become so familiar with it that they could direct its servicing with the consent of the operator.

They would also have to go over the engineering drawings for the existing system and the monitor system and install the monitor in a more permanently wired fashion with a simple switch disconnect. In short, the monitor system must get a long work out without constant attendance.

Such a system would cost about $10,000 to purchase and it would cost about $10,000 to install, operate, collect data and analyze the results. Such a program would take about one year.

It should be a detailed attempt to collect sufficient data to prove that the system can function trouble free and accurately.

The program would attempt to settle the question of how to deal with the difference between specification and what is delivered out of a manual plant, how much variation there would be between an automatic lever system and a load cell recording system, and how to deal with this discrepancy if any.

Up to this point the program has used borrowed equipment. This does not seem practical from here on. The equipment will be tied up for a long period of time and we doubt that any manufacturer will supply this gear on a loan basis under these circumstances.

Success of this program also depends largely on an atmosphere of cooperation between the representatives of the State and the plant operator. It is no small task to ask an operator that specification jobs as well as non-specification jobs be monitored over a long period of time. From our brief experience in trying to install the equipment for the last tests, it is obvious that even the best of plants will be found deficient in some area.

We have been very careful to avoid the question of whether or not we are creating a situation where we are confronting the scale iron system with a system meant to supplant it. We have made it perfectly clear that the State of California has no interest in promoting any weighing system. It is looking and has been looking for a monitoring system which will help the State, help the operator, simplify inspection and speed up payment. We have stated that the program is exploratory, that only some objectives may be achieved, perhaps none will be achieved. From the point of view of operator relationship this should be emphasized over and over.

A closing comment seems in order on the question raised and mentioned over and over again by plant manufacturers and plant operators, what to do with a discrepancy in the reported weights. It seems a fair guess that if the test program is continued and the cells continue to function as the manufacturers expect them to, there will be virtually no discrepancy to speak of when the scale irons are not malfunctioning. We have hesitated to say this outright at any point in the report. We feel it remains to be proven. But we feel that this conclusion at this point seems valid.

With regard to running this system at random, it can easily be done by the use of a timer. There appears to be no reason to do this since the system can keep up with the plant and it would appear to be useful to have the total record.

XII VOLUMETRIC MONITORING

With regard to volumetric plants, to the extent that they are now checked by weighing systems, the check weighing can be monitored by a load cell system. Since volumetric batching is not too common it is likely that the monitoring of these plants will require a little extra thought on a specific installation basis, but if they are now checked by a scale, the scale can be checked by load cells.

PART TWO

OF

A FINAL REPORT ON

"RECORDATION OF QUANTITIES OF MATERIALS

INCORPORATED IN

BASE AND PAVEMENT PLANT MIXTURES"

D. Additional Analysis of Test Data from Norman Pitt Study

Additional analysis of data generated in the Norman Pitt test is thought to be desirable for several reasons. First, the data provides a unique opportunity to examine in some detail the operational characteristics of an automated weigh batching plant--although operated manually--during a routine production run. Secondly, it is most important in this study to evaluate as accurately as possible the relationship of weights recorded by the different systems and the most probable true weight of aggregate in the test batches. Finally, reduction of the photographic record to a numerical printout permits preservation of the test data.

Reference is made to pages 17 through 26 of the report by Norman Pitt as set forth in Part One of this document. This material is summarized in part below as a basis for understanding the analysis presented in this section.

It will be remembered that a Howe-Richardson "Magna-Tronic" load cell weighing system was installed on a Madsen 6000 lb. Asphalt Concrete batching plant. Load cells were installed at the four corners of the aggregate weigh hopper between the main torque levers of the basic plant weighing system and brackets on the weigh hopper itself. An M-R Ticket Printer was provided with this system with its energizing circuit interlocked with the plant controls so that when any aggregrate feed gate is closed a 1½ second delay is introduced, when other aggregate feed gates cannot be opened to allow the system to come to rest and weight in the hopper to be printed.

Printed cards for approximately 145 batches were obtained with this equipment during the course of the final test on July 10, 1968.

At the same time these printed cards were obtained with the Howe-Richardson "Magna-Tronic" load cell weighing system a photographic record was made of the main plant aggregate scale dial indicator. This was accomplished through the services of a professional industrial photographer who utilized a 16-mm camera to take approximately 10 each frame sequences of the position of the needle on the plant aggregate scale dial indicator for each ingredient weighed.

Thus, for each test batch recorded a card with a single digital print-out of the load cell weight, for each aggregate size weighed, was obtained together with a length of 16-mm black and white film representing approximately 10 time-lapse motion pictures of the main plant aggregate scale dial indicator for each aggregate sized weighed. (Note: For most of the test batches the print-out for one aggregate size, i.e., ingredient number three, was omitted from the load cell print-out cards.)

There were four separate sizes of aggregate (ingredients) proportioned for each batch.

In order to analyze this data in more detail than attempted in the Norman Pitt report it was necessary first to translate the film record of the test batches into digital form. This was accomplished by projecting the film one frame at a time while reading and transposing the visual film presentation into a numerical print-out on adding machine tape.

Before discussing the analysis of this data it is necessary to understand the relation between film frames and batching cycle.

For the photographer to coordinate his film exposure with the batching cycle, at the moment the "Magna-Tronic" M-R Ticket Printer was energized, it was necessary to provide a visual signal. This was accomplished by splicing a normal light bulb socket into the electrical circuit so the light would come on when the printer circuit was energized. This, it will be remembered, is the instant when the aggregate feed gate for the particular aggregate size being weighed, and to be recorded, is closed. The first photograph on page 56 illustrates this arrangement.

When the signal light came on the photographer would start the camera and allow it to run for approximately 10 frames. This, it will be seen, resulted in systematic error induced because the first frame recorded on film usually occurred just prior to the moment that maximum inertial over travel of the dial indicator was reached. There was no means of identifying the exact point in time when the reading of the main aggregate scale dial indicator was equivalent to the reading of the load cell scale dial indicator and print-out.

For this analysis a total of 41 batches were selected which gave legible, directly comparable readings, except for ingredient number three, with equivalent load cell print-out values. The highest and lowest dial readings in each photographic sequence for each weighing cycle were extracted and plotted as an ogive form of frequency distribution. The mean of the highest and lowest dial readings for each weighing cycle was then similarly plotted as was the mean of all values for each weighing cycle. These ogive presentations appear on pages 41, 42 and 43.

F

Load cell values in all weighing increments of all plotted batches, except possibly 49, 53, 58 & 59 appear visually to be at or near the probable true value. Load cell values produce a straighter stemmed ogive for all weighing increments than either arithmetic mean. This could be expected because of the skewness described above.

A comparison of slopes and dispersion of the ogive curves was made. However, it is believed a visual comparison is just as valid, insofar as determination of probable true value. The standard deviation of all nine curves (load cell, mean of extremes and mean of all values for the three weighing increments) was very close to ± 18 pounds. The percentage variation of the mean of the individual curve from the mean of three curves was from -0.42% to flat as follows:

Percentage Variation From
The Mean Of All Three Curves

	Load Cell	Mean of Extreme	Mean All Values
1st Increment	-0.42%	+0.38%	Flat
2nd Increment	+0.14%	Flat	-0.18%
4th Increment	-0.17%	+0.15%	Flat

However, comparison of the mean of the 20% and 80% curve points with the 50% point value was exact in all cases with the load cell and varied from exact to a maximum 6-pound difference in the others, with a mean variation of 3½ pounds.

It is concluded a standard deviation of ± 0.2% is reasonable to assign to the load cell values in this installation.

It is also concluded that the practically constant standard deviation of ± 18 pounds for all curves for all increments of weighing is a reasonable measure of accidental variation of manual manipulation for this particular circumstance and installation. This is qualified by the fact that the plant is normally operated automatically, so data obtained during manual operation for this test should not be extrapolated to represent manually operated plants, generally.

E. Overall Conclusions and Recommendations

I. Conclusions

1. The Norman Pitt study supports a number of conclusions with respect to weigh batching plants used in highway construction.

   a. Installation of an independent means of monitoring and recording the weighing operations of existing manual or automated batching plants, without reference to existing lever systems and necessitating no major modification of the primary weighing or control equipment, is clearly feasible.

   b. A load cell weighing system provides the best means of thus independently monitoring operation of the primary plant weighing and control equipment.

   c. Automatic digital recordation of weight data generated by load cell weighing systems is well within the existing "state-of-the-art" of batch plant instrumentation.

   d. Load cell weighing equipment of comparable accuracy to that of the mechanical lever scales commonly used in primary plant weighing systems, under normal conditions of installation and operation, is presently available on the competitive market.

   e. A load cell monitoring system can be made independent of most accidental and deliberate errors in the primary plant weighing system.

   f. Operational limitations, if any, of load cell weighing systems for routinely monitoring the complete batching operations in plants commonly used in highway construction have not been adequately established.

   The test installation described was undertaken only to evaluate feasibility of concept. It was not designed nor intended to explore possible practical limitations in application. For example, load cells were installed on the aggregate hopper but not on the asphalt bucket and only one day of pl... operation was monitored. Results cannot, therefore, reasonably be extrapolated as proof of ultimate practicality or suitability.

2. Feasibility of independently monitoring and recording proportioning operations of weigh batching plants without reference to existing lever systems permits contracting agencies a fresh approach to the problem of writing specifications. It thereby becomes reasonable to consider requirements directed primarily to end result performance of the plant, as evidenced by output of the monitoring and recording system, rather than to the equipment, methods and controls of the primary plant weighing system.

This has a number of important advantages. These include permitting use of existing manual or partially automated plants where appropriate, flexibility in the plant owner's selection of control equipment, greater incentive for improvement of primary plant controls and weighing systems, and many others.

3. Independent load cell monitoring systems installed without reference to existing lever systems on weigh batching plants may come to have an important secondary function in the calibration of the primary weighing systems. However, an amendment of weights and measures code provisions may be necessary to enable this application of the equipment.

4. Digital records of weight data generated by load cell monitoring systems have possible but unexplored use as pay documents in the cases of asphalt concrete mixtures and others.

5. The Norman Pitt study does not attempt to appraise in any detail the feasibility of monitoring and recording the operation of volumetric proportioning plants except with respect to existing check weighing systems on such plants. This does not appear to warrent further investigation at this time owing to the comparatively limited use of such plants.

6. Scope of application with respect to independent monitoring and recording systems for weigh batching plants used in highway construction has not been

determined, i.e., should independent monitoring and recording systems be used only on plants without other provision for recordation, or should independent monitoring and recording systems be used on all weigh batching plants?

7. Further research into application of independent monitoring and recording systems utilizing load cells and digital recordation is amply justified by the results of this feasibility study.

II. Recommendations

The basic recommendation of the Norman Pitt report, that a carefully engineered load cell monitoring and recording system be installed in a modern, fully automated asphalt concrete plant and thoroughly tested over a significant period of time, is sound and should be implemented.

The system, patterned on that developed in the feasibility study, should be designed to monitor all weighing operations of all ingredients in a modern, fully automated asphalt concrete plant. The plant selected for this installation should be equipped for digital recordation of data generated by the primary plant weighing system and the load cell monitoring system should be designed with its independent digital recording system. The print cycle for the load cell monitoring system should be interlocked with the print cycle for the primary plant weighing system in a manner such that the weight data printed by the two recording systems will be directly comparable. Additionally, arrangements should be made to obtain accurate platform scale weights of a sufficient number of loads of mix produced in the plant during the test period to verify weights recorded during the batching operation..

A plant where the weigh hoppers and scale levers are enclosed within a housing would be preferable because it would create a more adverse environment with respect to heat and dust.

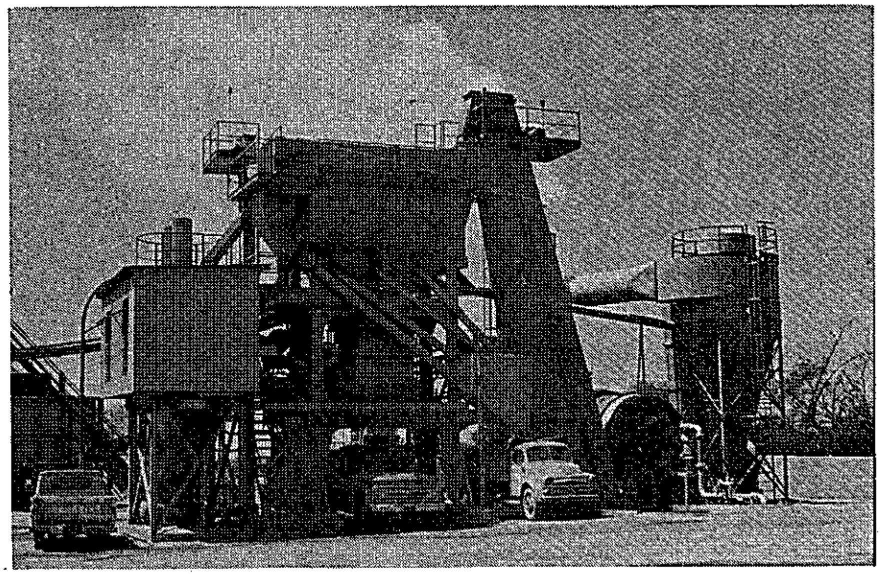
The test program for this installation should extend over a long enough period of time and plant activity to provide reliable information as to operating costs, maintenance requirements, accuracy, calibration requirements and mechanical suitability.

Despite the fact that important potential application of such systems would be on manually or partially automated plants, testing a load cell monitoring and recording system on a fully automated plant is the most practical way to satisfy the immediate need to develop documentation as to any differences between primary plant mechanical lever weighing systems and the load cell monitoring system when operated under identical conditiona. The difficulty in developing such documentation is well illustrated in the effort to analyze the data generated by tests performed during the Norman Pitt study.

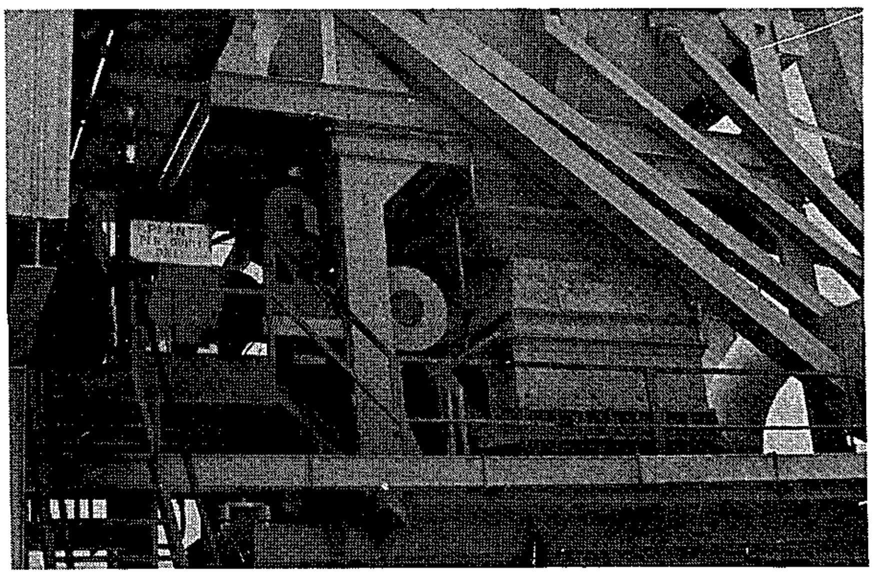
Furthermore, testing the proposed monitoring and recording system on a modern, fully automated plant will provide information necessary for a resolution of the important question regarding the potential scope of application of monitoring and recording systems, as discussed in our sixth conclusion. This may be a decisive factor as to the nature of subsequent research.

In summary, it is now believed that the total research effort needed will consist of three principal phases; a feasibility study, a determination of practicality and finally, a resolution of application problems. The feasibility study is now complete and is the subject of this report. It has successfully carried the research to a point beyond that originally contemplated. The next phase is described in the recommendations above. If the results of this work are also favorable, there will be need for the third phase to resolve problems that can reasonably be anticipated in applying this concept to the variety of plants encountered in practice.

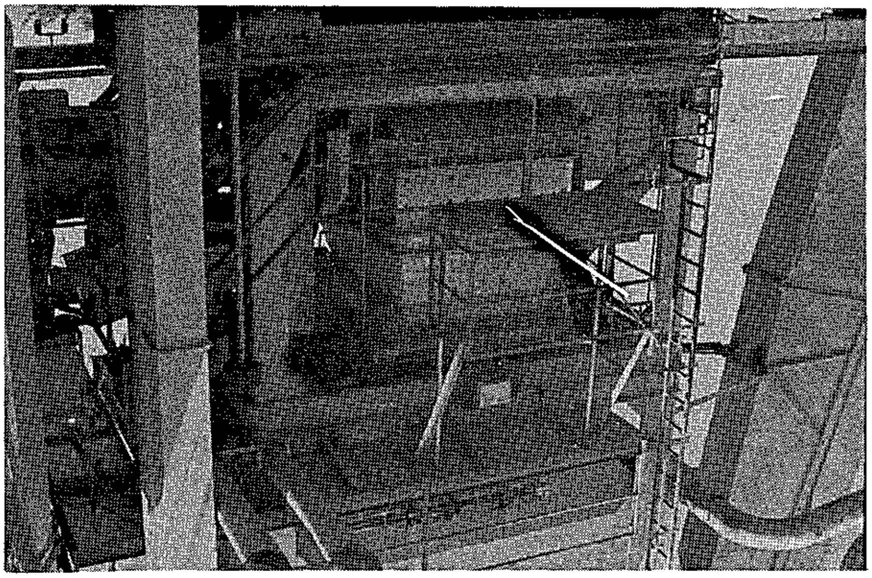
F. Photographs of Norman Pitt Test Installation



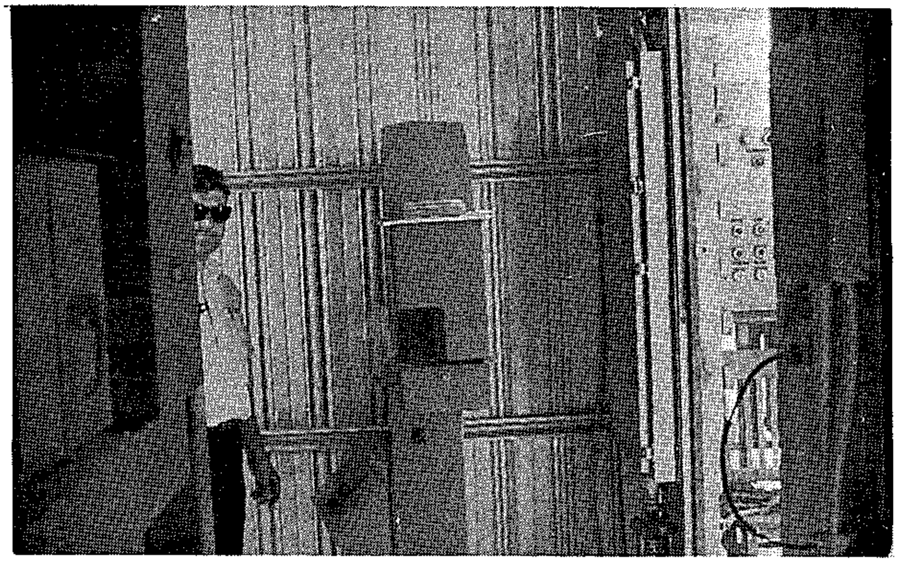
Overall View of the Plant



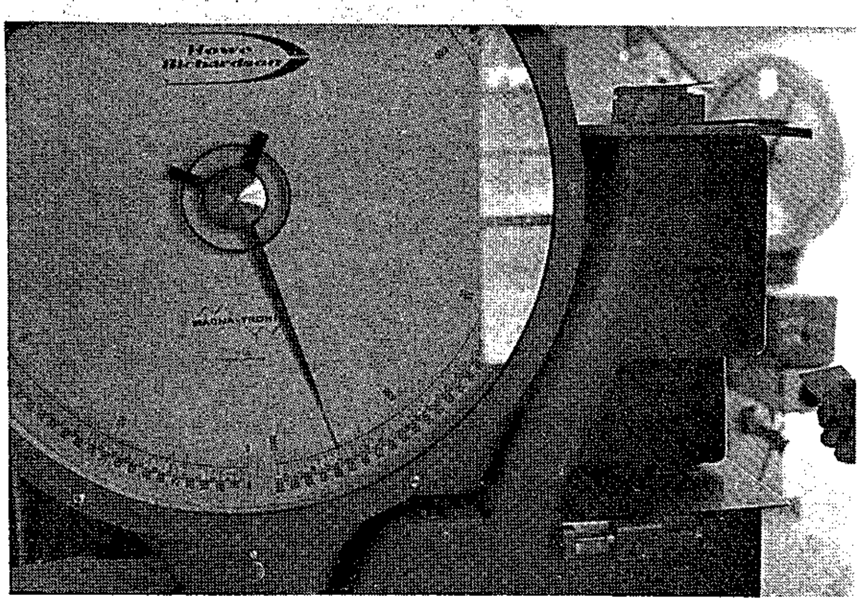
Operator's Platform - Front View



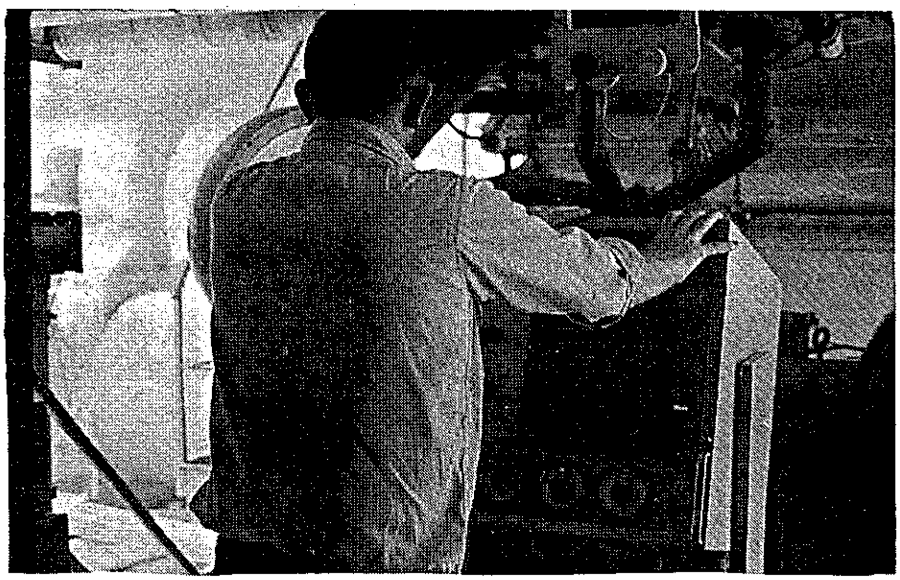
Operator's Platform - Rèar View



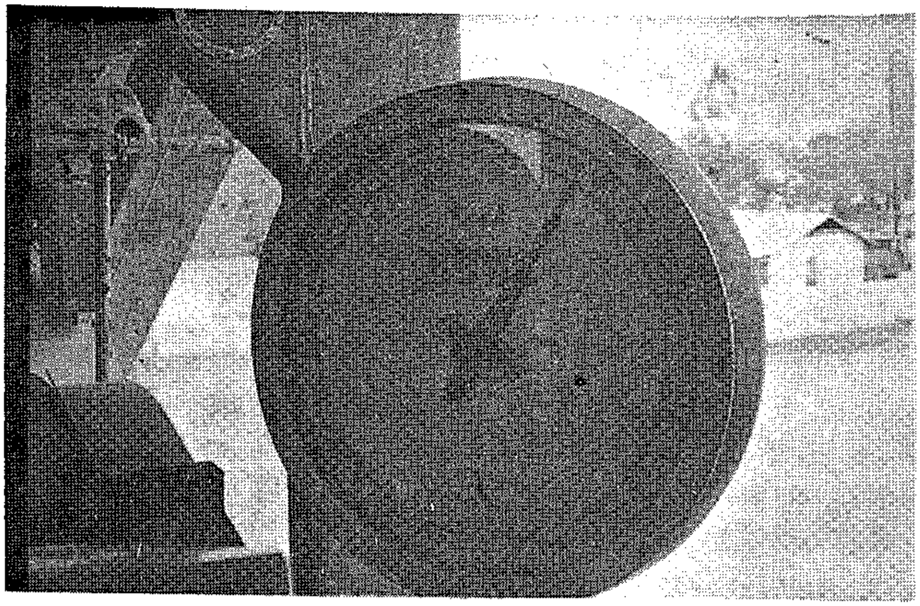
Magna-Tronic M-R Printer



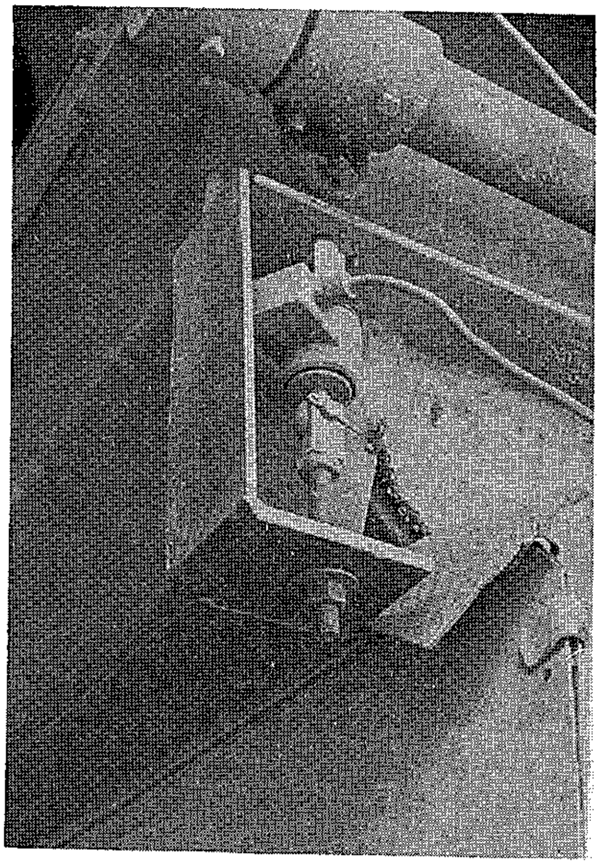
Closer View of M-R Printer



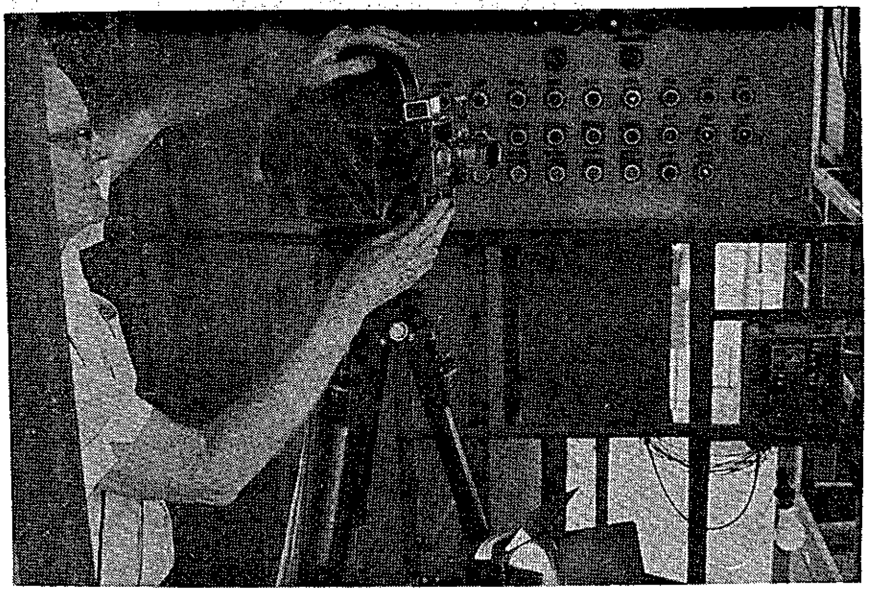
Operator's Console



Main Plant Aggregate Scale Dial



Load Cell and Bracket



Camera and Signal Light

Test Weights